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TRED HF COMMUNICATION SYSTEM ANALYSIS

Design technique is based on obtaining equality of quasi-minimum atmospheric noise and receiver internal noise at the receiving subsystem input.

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Research and Development

24 September 1971

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PROBLEM

Establish the electrical performance characteristics required in hf communication equipments for successful operation on naval ships. Establish design parameters needed to maximize usable sensitivity and to minimize degradation due to on-site interaction between equipments operated simultaneously.

RESULTS

1. A design technique is established and applied to three representative system arrangements. It is based on obtaining equality of quasi-minimum atmospheric noise and receiver internal noise at the receiving subsystem input.

2. Transmitter broadband noise is the most serious impediment to achievement of a system permitting 2½% minimum frequency separation between transmitting and receiving frequencies and 5% minimum separation between transmitting frequencies used simultaneously. With current transmitter performance about 8% separation between transmitting and receiving frequencies is needed.

3. Transmitter intermodulation products and harmonic radiations will cause spot frequency interferences, depending on the frequency plan. These interferences will fall on exactly the same frequencies that antenna environment-generated intermodulation products fall on, and are of comparable magnitude.

RECOMMENDATIONS

1. Apply the basic analysis techniques established here to other situations and platforms as required.

2. Investigate possible methods of reducing transmitter broadband noise to permit attainment of 2½% minimum transmit-to-receive frequency separation.

3. Leave third-order intermodulation product and harmonic frequencies unassigned in frequency plan whenever feasible. Extensive, and possibly expensive, measures to reduce transmitter intermodulation product and harmonic generation do not appear to be justified until the shipboard antenna environment can be further improved.

ADMINISTRATIVE INFORMATION

This work was performed under X32-83, Task 10184 (NELC J548), by members of the Radio Technology Division. This report represents partial coverage of work performed between 1 July 1970 and 15 July 1971 in the TRED* program and was approved for publication 24 September 1971.

*Transmitter and Receiver Equipment Development.

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INTRODUCTION

This report is a detailed exposition of the procedure which must be followed to define clearly and quantitatively the performance characteristics of an hf communication system aboard ship. (Although magnitudes of individual parameters will vary, the same sequence can be used to investigate a similar system on any limited platform.)

After a reference system displaying the desired performance is analyzed, the procedure is applied to a system composed of existing transmit and receive equipments by utilizing measured data. Critical results pinpointing weaknesses which limit communications performance are discussed with possible modifications to remove the limitations. Finally, a short summary lists the shortcomings and solutions with no detailed comment.

Emphasis is on the interaction between various system parameters which have important bearing on the ability to receive incoming traffic accurately in spite of the potential direct or indirect interference on the receiving subsystem by simultaneous operation of the transmitting subsystem. Every effort is made to protect the receiving capability by carefully establishing tradeoffs, which would be unnecessary were the transmit and receive subsystems more widely separated.

As an aid in understanding the relationship of the subsystem components, five simplified charts are provided. Three are useful for the situation in which receive and transmit subsystems are on separate antennas; the other two refer to the common use of a single antenna for both transmitting and receiving, covering both transceive and nontransceive conditions.

In the interest of clarity, no consideration is given in this report to the interference potential from or to other systems on the same ship at other frequency bands. Discussion is limited to intrasystem performance. Thus, the frequency range considered is only between 2 and 30 MHz. This is referred to as the 'hf' band, although it is more properly the 'mf/hf' band.

A basic criterion followed in the system design is that the receiver output due to the signal plus atmospheric noise input $(S + N_A)$ shall not be impaired by more than 3 dB by internal receiver noise or by any system-related interference. This condition exists when the receiver internal noise and the quasi-minimum atmospheric noise are made equal at the receiving subsystem input. It is assumed that currently existing types of transmitting and receiving multicouplers must be used, since recent designs appear to achieve near-optimum balance of electrical characteristics. Transmitters are assumed to have a maximum output power rating of 1 kW rms, 2 kW PEP (peak envelope power). A correction factor may be applied for any transmitter of higher power rating. The basic design goal is to achieve satisfactory system operation with a minimum separation of 2½% between receiving and transmitting frequencies used simultaneously and 5% between transmitting frequencies.

ANALYSIS PROCEDURE

The general procedure is given in this section for the analysis of the shipboard hf communication system to establish needed performance and equipment parameters. When representative values for system element characteristics are inserted, some of the equipment parameters will be obtainable with currently available equipments and some may not be. Modifications of the basic system design then are considered, as feasible, to obtain realistic equipment parameters providing maximum usable receiving system sensitivity under quasi-minimum atmospheric noise conditions with minimum interference from local transmissions.

SEPARATE TRANSMITTING AND RECEIVING ANTENNAS

The initial analysis is based on a minimum of 5% frequency separation between transmitters and 2½% frequency separation between receivers. Transmitters are connected to one antenna through a transmitting multicoupler, and receivers are connected to a second antenna through a receiving multicoupler. Simultaneous operation is assumed. Figure 1 displays the system arrangement. The analysis is based on matching the quasi-minimum atmospheric noise level to the receiver internal noise level at the receiving subsystem input. The internal noise (noise figure) of the receiver is translated to the receiving subsystem input by adding the on-channel insertion loss of the receiving multicoupler. The quasi-minimum atmospheric noise level is then

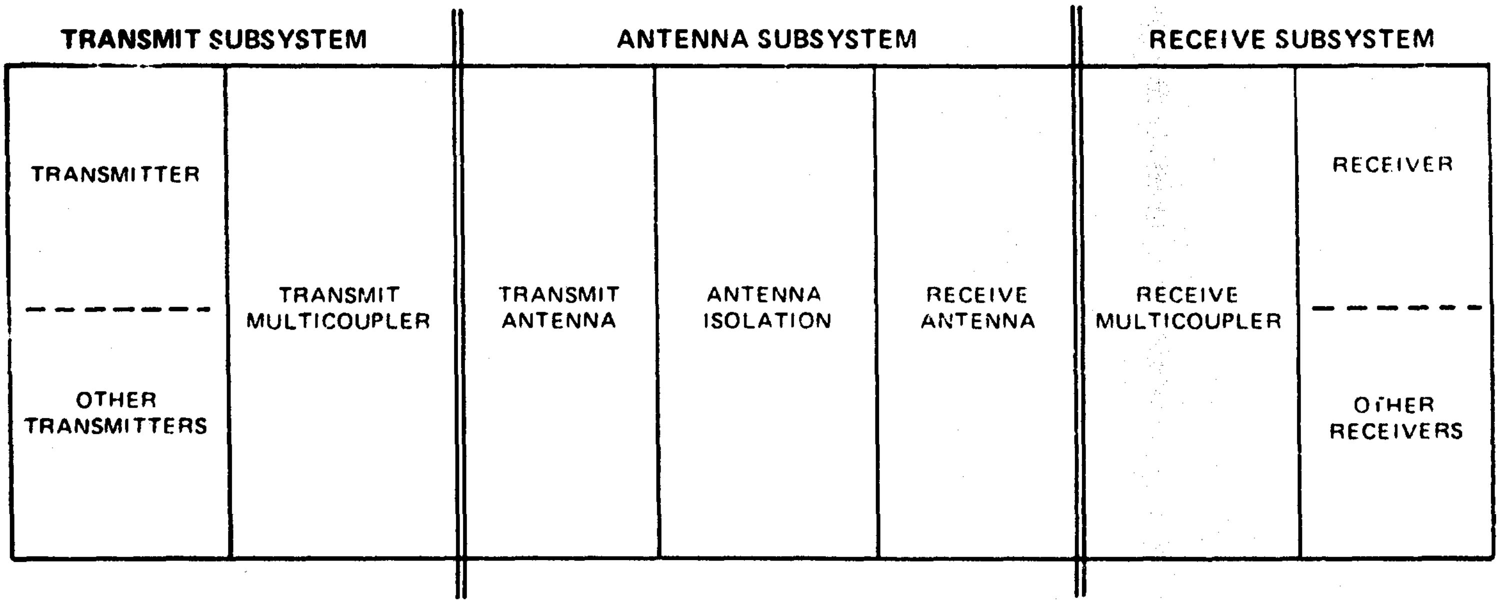

Figure 1. System with separate receive and transmit antennas.

compared, frequency by frequency, with the receiving subsystem noise. The difference is equal to the receiving antenna deficiency (performance below that of an ideal antenna) which will provide equality of the quasi-minimum atmospheric noise and receiver noise power at the receiving multicoupler input. The maximum permissible receiving antenna deficiency without excessive degradation of effective receiving sensitivity is desirable. This reduces the interference effect of local transmissions. When atmospheric noise and receiver internal noise are equal at the reference point, the receiving subsystem input, the (S + N)/N ratio at the receiver output is impaired by 3 dB.

It is assumed that the interference effects from local transmissions – such as cross modulation, desensitization, and receiver intermodulation – all occur in the receiver at approximately the same interfering power level. Then all are adequately represented by a limit on cross modulation. A maximum interfering power level at the receiver input terminals for satisfactory cross modulation performance is established. The nearest transmitting frequency to the receiver on-channel frequency is 2½% away. At this frequency separation from the transmitter frequency, the attenuation of all elements between the transmitter output terminals and the receiver input terminals is totaled. The total attenuation must equal the difference between the transmitter rated power output and the cross modulation power limit at the receiver input terminals. The total attenuation consists of the sum of the transmitting multicoupler on-channel insertion loss, the transmitting-to-receiving antenna isolation, the receiving antenna deficiency, and the receiving multicoupler rejection at 2½% off channel. The transmitting-to-receiving antenna isolation required can be determined, since the other factors have been established by measurement or by calculation. If the actual antenna isolation values, specified or achieved, equal or exceed the derived values, receiving system performance impairment due to cross modulation will not exceed 3 dB.

This procedure has established two parameters in the system design: first, the antenna deficiency required to match quasi-minimum atmospheric noise and receiver internal noise to achieve maximum usable receiving subsystem sensitivity within 3 dB; and second, the transmitting-to-receiving antenna isolation required to keep the level of impact of transmitting fundamental power at the receiver down to the receiver internal noise level.

These two antenna system parameters, or equivalent specified values, are incorporated in the system design. The limits on the permissible levels of spurious outputs from the transmitter – such as broadband noise, harmonics, and intermodulation products – are established by tracing levels through the system from receiver input to transmitter output. The criterion used is again that the interference levels may not exceed the level of the interference due to receiver internal noise at the receiver input. Since periods of minimum atmospheric noise and the other interference effects have time diversity, they are unlikely to occur simultaneously, so the performance degradations seldom add. The complete system is then checked for power levels that the receiving multicoupler and the receiver must withstand.

An alternative analysis procedure is possible. Limits at the receiver input for interference due to spurious transmitter radiations can be set as before. Instead of translating these limits back to the transmitter output terminals and using the limits as requirements on transmitter characteristics, we can assume the spurious levels at the transmitter output and carry the path attenuation analysis from the transmitter output to the receiver input. A comparison then is made between the interfering radiation levels thus derived and the limits established for permissible levels at the receiver input. This method of analysis tends to focus attention on receiving subsystem performance deficiencies, rather than on transmitting subsystem performance deficiencies as does the first method of analysis.

A special case exists when transmitters or receivers are used on separate individual whip antennas without multicouplers. In the transmitting case the selectivity that a transmitting multicoupler normally supplies is only partially replaced by the antenna tuner. The missing selectivity must be replaced by a tunable filter of equivalent characteristics if system performance is not to be impaired. In the receiving case a filter having the same electrical characteristics as one channel of a receiving multicoupler is required. Figures 2 and 3 present schematic diagrams of two arrangements that may occur.

It is recognized that this analysis procedure has its accuracy limitations. The electrical characteristics of the system elements are those measured with 50-ohm terminations. In an actual system with variable and unknown cable lengths between elements, and particularly at the off-channel frequencies at which many interference effects occur, several impedance mismatches exist. Some of these are deliberate and some are inadvertent. A complex system situation exists. This could be completely analyzed only if additional measured data were available, and then only for a specific ship.

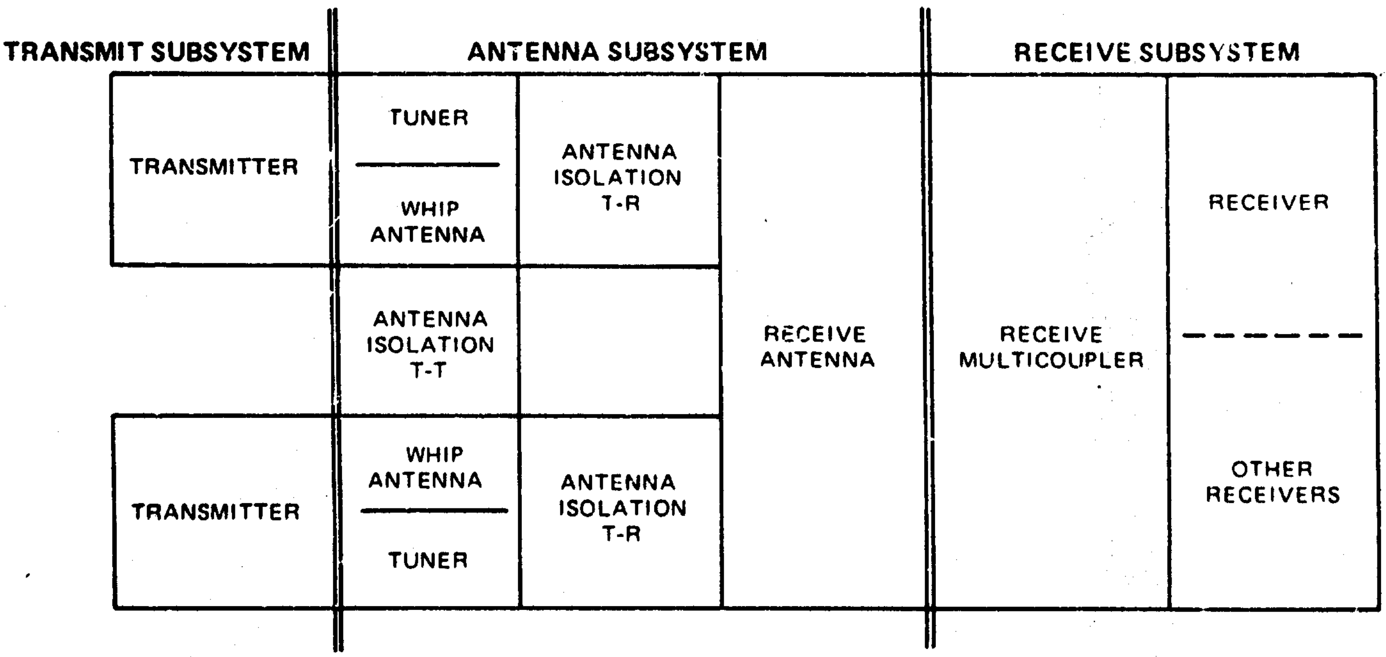

Figure 2. System with separate receive and transmit antennas (whip antennas for transmit).

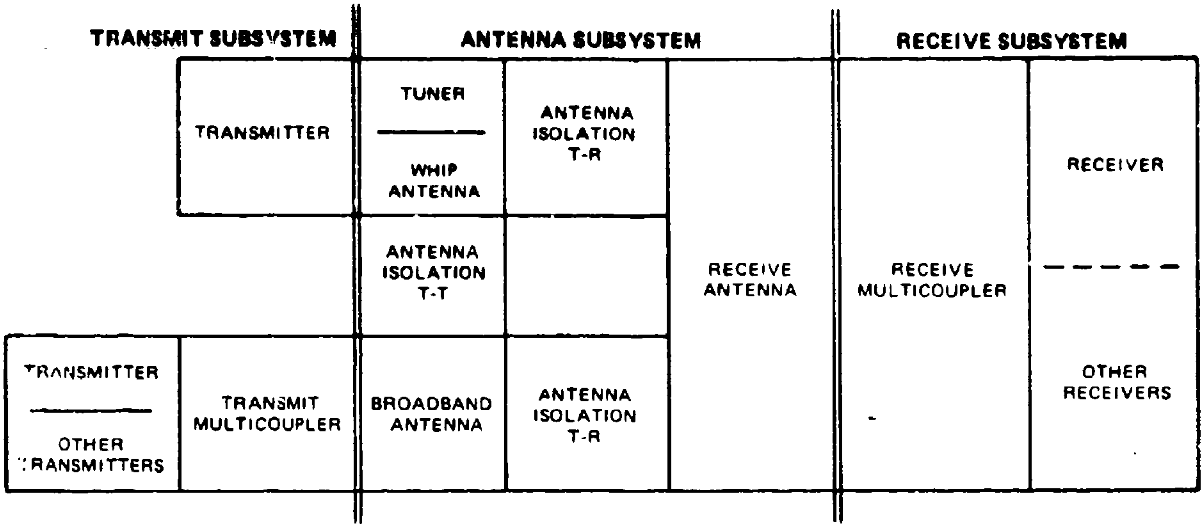

Figure 3. System with separate receive and transmit antennas (whip and broadband for transmit).

COMMON TRANSMITTING AND RECEIVING ANTENNA: TRANSCEIVER OPERATION

In the usual situation several transceivers are multicoupled to a common antenna. A transmit/receive relay is used with each transceiver to isolate the transmitting and receiving functions. The transmitting multicoupler is utilized during both transmission and reception. No receiving-type multicoupler is included. Figure 4 displays this arrangement.

The antenna, since it is used for transmitting, must have as high an efficiency as possible. Antenna deficiency can no longer be incorporated as a protection factor. The on-channel insertion loss of a receiving multicoupler also is no longer available – only the very much smaller insertion loss of the transmitting multicoupler. The missing attenuation of these two system elements is replaced by a fixed decoupling network having the equivalent attenuation-versus-frequency characteristics. The analysis of the complete system is conducted as before, including the decoupling network. Remember that now there is no transmitting-to-receiving isolation. Also, with a transceiver, since transmission and reception take place on the same frequency, the minimum transmitting-to-receiving frequency separation is equal to the minimum transmitting-to-transmitting frequency separation, or 5%.

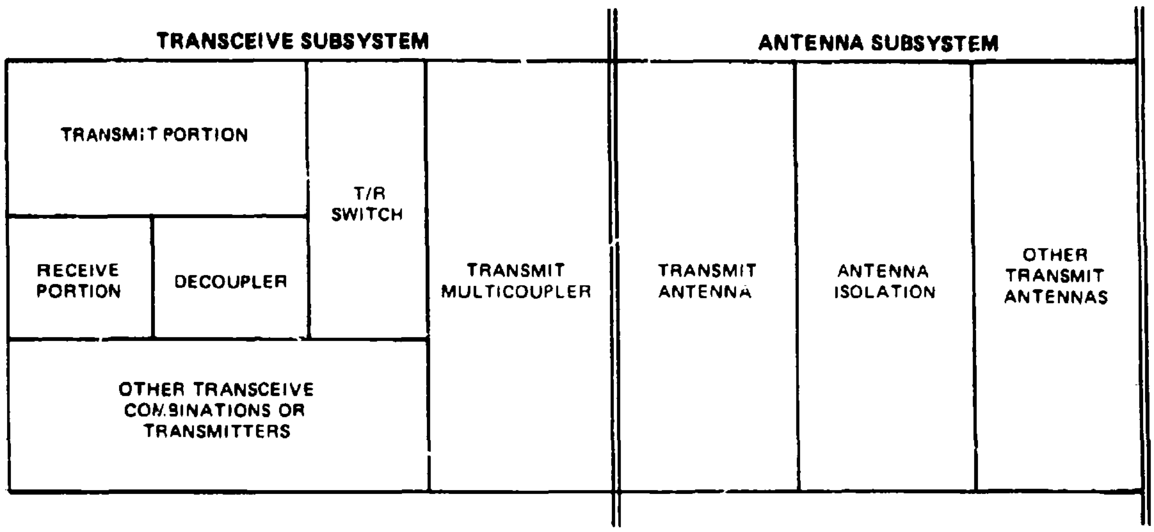

Figure 4. System with common antenna, receive and transmit (transceive case).

In instances in which multicouplers are not used and there is only one transceiver per antenna, the analysis is somewhat different. Now in the receiving subsystem a fixed decoupling network is needed to replace the receiving antenna deficiency, and, in addition, a tunable filter is needed having the same characteristics as one channel of a receiving multicoupler. In the transmitting system a tunable filter is needed having the same characteristics as one channel of a transmitting coupler. With these elements added, the analysis proceeds as in the separate-antenna case.

COMMON ANTENNA FOR RECEIVING AND TRANSMITTING: NON-TRANSCEIVE OPERATION WITH RECEIVING MULTICOUPLER

Another possible arrangement is to use a common antenna for both transmitting and receiving but to use separate transmitters and receivers instead of a transmit/receive relay and a transceiver. The transmitters are connected to the common antennas through transmitting couplers and the receivers are connected to the same antenna through receiving couplers and a fixed decoupling network. Figure 5 displays this arrangement.

With this arrangement a fixed decoupling network must be included in the receiving subsystem to replace the receiving antenna deficiency, which no longer exists, since an efficient transmitting antenna is used for receiving. This network differs from that in the first case, since now a receiving multicoupler is included and its on-channel insertion loss is not provided by the decoupling network. The analysis proceeds as in the separate-antenna case. Remember that the transmitting-to-receiving antenna isolation no longer exists. The minimum transmitting-to-receiving frequency separation is 2½%.

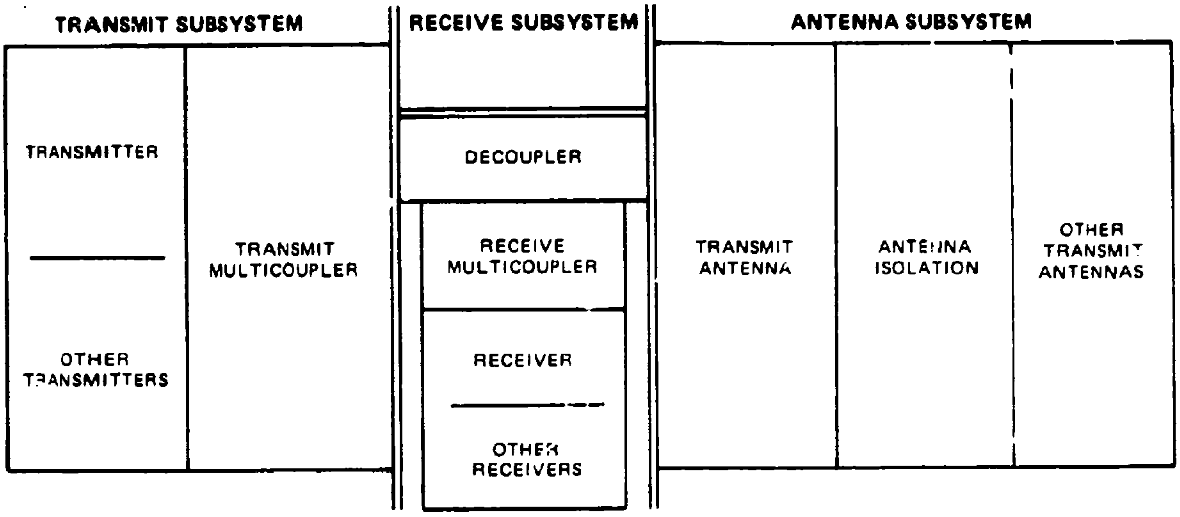

Figure 5. System with common antenna, receive and transmit (nontransceive case).

ALTERNATIVE SYSTEM ARRANGEMENTS

These analyses, when numerical values representative of current systems are inserted, may lead to situations in which unrealistic requirements are derived for equipment or antenna system characteristics. In such cases the effects of possible modifications in antenna arrangements or minimum channel separations will be considered.

NUMERICAL ANALYSIS OF SYSTEMS

BASIC ASSUMPTIONS MADE IN THIS SECTION

The transmitting multicouplers selected for inclusion in the system are the AN/SRA-56/57/58 Antenna Couplers having a power-handling capability per channel of 1 kW rms, 2 kW PEP. The receiving multicouplers are the AN/SRA-38/39/40/49 Antenna Couplers. Measured values of the on-channel insertion loss, and the rejection at frequencies 2½% and 5% from the on-channel frequency, are given in table 1 for these couplers. For large frequency separations, such as occur when harmonics are considered, the minimum attenuation of the transmitting couplers is taken as 60 dB.

TABLE 1. ATTENUATION CHARACTERISTICS OF ANTENNA MULTICOUPLERS.

(Col. 1) Tuned Freq, MHz	(2) On-channel Insertion Loss, dB	Off-channel Frequency Rejection (3) 2½% dB	(4) 5% dB	(5) 10% dB
AN/SRA-38/39/40/49 Receiving Couplers				
2	14	56	80	104
4	12	49	73	97
6	10	45	69	93
8	9	43	67	91
10	8	41	65	89
12	8	39	63	87
15	7	37	61	85
20	6	34	58	82
25	5	32	56	80
30	4	30	54	78
AN/SRA-58/59/60 Transmitting Couplers				
2 to 30	2	28	40	52

(For frequencies much greater than 10% off channel, minimum rejection is assumed 60 dB.)

The quasi-minimum atmospheric noise levels are based on two sources: a comprehensive examination of expected noise at many locations and for all seasons using data from the National Bureau of Standards noise measurement program; and shipboard measurements made at sea in the San Diego area (a typical low-noise region). The quasi-minimum values are based on judgment rather than on specific computations. They represent typical low periods in some of the lower-noise regions, but not at high latitudes. Values are shown in table 2. They are expressed in dB above thermal reference for a 3-kHz bandwidth, -139 dBm, and in dB with respect to 1 milliwatt.

TABLE 2. QUASI-MINIMUM ATMOSPHERIC NOISE LEVELS.
(dB ABOVE THERMAL, 3-kHz BANDWIDTH, -139 dBm).

(Col. 1) Freq, MHz	(2) Level, dB Above Thermal	(3) dBm
2	52	-87
4	44	-95
6	39	-100
8	36	-103
10	33	-106
12	31	-108
15	28	-111
20	25	-114
25	22	-117
30	20	-119

The receiver used as representative of current equipments is the R-1051-D/URR Radio Receiver; and the transmitter used is the AN/URT-23 Radio Transmitter with 1-kW rms, 2-kW PEP output power.

It is assumed that the internal noise of the receiver is 12 dB above thermal noise in a 3-kHz bandwidth (a noise figure of 12 dB). This corresponds to a noise power level of -127 dBm. It is equivalent to a receiver sensitivity of 0.67 microvolt from a 50-ohm source for a 10-dB (S + N)/N receiver output.

ANALYSIS OF SEPARATE-ANTENNA CASE

(1) ESTABLISHMENT OF ANTENNA DEFICIENCY (TABLE 3)

The antenna deficiency is determined by combining the receiver noise figure (table 3, column 2) and the on-channel receiving multicoupler insertion loss (table 3, column 3) to obtain the variation with frequency of the receiving subsystem noise level at the multicoupler input (table 3, column 4). To match the receiving subsystem noise level at the multicoupler input (table 3, column 4) to the atmospheric noise level (table 3, column 5) as required by the fundamental design assumption made, an antenna deficiency (table 3, column 6) is needed. The values of antenna deficiency will preserve the maximum usable receiver sensitivity at times of quasi-minimum atmospheric noise without an unnecessary response to local transmitter radiations.

TABLE 3. DETERMINATION OF ALLOWABLE ANTENNA DEFICIENCY.

(Col. 1) Freq, MHz	(2) Rcvr Noise, dBm	(3) Cplr Loss, dB	(4) Noise at Subsys Input, dBm	(5) Atmos Noise, dBm	(6) Ant Deficiency, dB
2	-127	14	-113	-87	26
4	-127	12	-115	-95	20
6	-127	10	-117	-100	17
8	-127	9	-118	-103	15
10	-127	8	-119	-106	13
12	-127	8	-119	-108	11
15	-127	7	-120	-111	9
20	-127	6	-121	-114	7
25	-127	5	-122	-117	5
30	-127	4	-123	-119	4

(2) ESTABLISHMENT OF TRANSMITTING-TO-RECEIVING ANTENNA ISOLATION (TABLE 4)

Receiver performance shall not be reduced more than 3 dB as a result of cross modulation, intermodulation, or desensitization in the receiver caused by undesired local signals. The interfering power limit assumed is not to exceed 0 dBm at the receiver input terminals at a frequency 2½% from the receiver on-channel frequency.

The difference between the susceptibility of the receiver to interfering signals, 0 dBm, and the transmitter average radiated power level is 58 dB (2-dB loss in the transmitting multicoupler and cables deducted). The gap between the needed total rejection (table 4, column 7) and the sum of the calculated antenna deficiency (table 3, column 6), the rejection provided by the receiving multicoupler (table 1, column 3), and the transmitting multicoupler on-channel loss (table 4, column 3) yields the additional isolation required (table 4, column 8).

TABLE 4. ANTENNA ISOLATION DETERMINATION.

(Col. 1) Freq, MHz	(2) Xmtr Output, dBm	(3) Xmtr Cplr Loss, dB	(4) Rcvr Cplr Loss, 2½%, dB	(5) Ant Def., dB	(6) Total Loss, dB	(7) Needed Total, dB	(8) Ant Isolation Reqd, dB
2	60	2	56	26	84	60	-24
4	60	2	49	20	71	60	-11
6	60	2	45	17	64	60	-4
8	60	2	43	15	60	60	0
10	60	2	41	13	56	60	4
12	60	2	39	11	52	60	8
15	60	2	37	9	48	60	12
20	60	2	34	7	43	60	17
25	60	2	32	5	39	60	21
30	60	2	30	4	36	60	24

To operate with a frequency separation of 2½% between transmitting and receiving frequencies used simultaneously, the receive-to-transmit antenna isolation expressed in dB as a function of frequency should be at least the values given in table 4, column 8. Negative values indicate a margin above requirements and a better performance than the 3-dB impairment used as reference.

An alternative approach to the system design is to fix the antenna isolation at selected values. If this is done, the impairment of system performance with respect to cross modulation, etc., will be better or worse than the 3-dB limit assumed. The change will be measured by the excess or deficiency of the selected values with respect to the values calculated in table 4. Or the receiver performance impairment limit may be held constant at 3 dB and the receiver parameter requirement of 0 dBm for cross modulation performance relaxed or raised in accordance with the excess or deficiency resulting from the selected value of antenna isolation.

(3) RECEIVER SPURIOUS RESPONSES

Two other forms of interference caused by the impact of external unwanted signals on the receiver are spurious and image responses. Both of these are, unlike cross modulation, the result of specific relationships between the frequency of the external signal and those signals from oscillators inside the receiver necessary for superheterodyne reception. They represent a smaller threat than does cross modulation because of their spot frequency nature. They tend to be located within a few percent of the receiving frequency when reasonably effective filtering is used ahead of the receiver.

In a system designed with frequency separations, antenna characteristics, and selectivity adequate to control cross modulation and related interferences, receiver spurious responses should seldom be a problem. Few will occur if transmitters are spaced 2½% or more from the nearest receiver operating frequency.

(4) RECEIVER INTERMODULATION

Intermodulation in a receiver results from two or more strong interfering signals entering the receiver input simultaneously. In most instances, the strongest of these signals will be from transmitters located on the same ship as the receiver. Normally, the frequency separation between transmitting frequencies will be 5% or greater. With this constraint, a receiver cannot be on an adjacent frequency that results in low-order intermodulation unless it is spaced from the nearest transmitter by 5% and from a second transmitter by 10%.

Rejection of the receiving multicoupler varies with frequency from 80 dB to 54 dB at 5% (table 1, column 4) and from 104 dB to 78 dB at 10% (table 1, column 5) off frequency. This should be sufficient attenuation to bring the interfering power levels at all frequencies below the allowable limit at the receiver input, estimated from limited measurement data at approximately 13 dBm.

(5) LIABILITY TO BURNOUT DAMAGE (TABLE 5)

If the receiving subsystem frequency coincides with a local transmitter frequency, there might be a problem from the possibility of receiving multicoupler or receiver damage. This condition will occur only during tuning operations or inadvertent misoperation. During normal operation, with the nearest transmitter separated 2½% from the receiving frequency, the receiving multicoupler will be exposed to the same power levels as those to be calculated for abnormal operation, but the receiver will be additionally protected by the receiving coupler selectivity at 2½% off frequency.

The radiated power of a 1-kW rated transmitter is 630 watts (+58 dBm), since 2 dB is assumed lost in the transmitting coupler and cabling. The total attenuation from the transmitting antenna to the receiving coupler input is the sum of the receiving antenna deficiency (table 3, column 6) and the receive-to-transmit antenna isolation (table 4, column 8). The power levels are attenuated further by the receiving multicoupler on-channel insertion loss (table 3, column 3) before reaching the receiver input terminals.

The maximum impact level is at a frequency of 8 MHz and is 43 dBm (20 watts) at the receiving coupler input and 34 dBm (2.5 watts) at the receiver input terminals. Should the nearest transmitter be at 2½% frequency separation, the maximum level that the receiving multicoupler must withstand remains 20 watts, but the receiver exposure is reduced by 43 dB, or to a power level of -9 dBm (0.00013 watt).

TABLE 5. DETERMINATION OF RECEIVING SUBSYSTEM PROTECTION LEVELS.

(Col. 1) Freq, MHz	(2) Rad. Power, dBm	(3) Rcvr Ant Def., dB	(4) Ant Isolation, dB	(5) Total Loss, dB	(6) Level at Cplr, dBm	(7) Rcvr Cplr Loss, dB	(8) Level at Rcvr, dBm
2	+58	26	0(-24)	26	+32	14	18
4	58	20	0(-11)	20	38	12	26
6	58	17	0(-4)	17	41	10	31
8	58	15	0	15	43	9	34
10	58	13	4	17	41	8	33
12	58	11	8	19	39	8	31
15	58	9	12	21	37	7	30
20	58	7	17	24	33	6	27
25	58	5	21	26	32	5	27
30	58	4	24	28	30	4	26

Should a 5-kW transmitter be included, these figures should be raised by 7 dB. Should a value of antenna isolation be specified, instead of being derived, as were the values in table 5, column 4, correction factors can be applied.

(6) TRANSMITTER SPURIOUS RADIATIONS, GENERAL

In addition to the desired fundamental output of the transmitter, there are several possible undesired radiations on frequencies separate from the transmitting frequency. Examples of these are transmitter broadband noise, transmitter-generated intermodulation products, harmonics, and other spurious radiations. These radiations, while weaker than the fundamental, can impair receiver performance whenever they fall on a receiving frequency.

Two different approaches can be used in the analyses. One is to set acceptable limits of receiver performance impairment due to these radiations at the receiver input terminals and carry the requirements back through the antenna system to the transmitter output. This approach tends to emphasize the transmitter shortcomings. The second approach is to use realistic or measured values of the spurious outputs of transmitters, carry these levels forward through the antenna system to the receiver input, and compare these levels with the receiver tolerance. This approach tends to emphasize the deficiencies of the receiving system, especially the antenna system. Little can be done in the receiving multicoupler or receiver, since the interferences are on the receiving frequency.

(7) TRANSMITTER BROADBAND NOISE (TABLE 6)

The minimum receive-to-transmit frequency separations aboard ship will be 2½%. The level of the transmitter broadband noise permitted in a 3-kHz bandwidth at the transmitter output must be limited to values such that the total attenuation between the transmitter output terminals and the receiving subsystem input terminals shall reduce the broadband noise to the

the atmospheric noise level at that point. The total attenuation is comprised of the transmit multicoupler rejection at 2½% off frequency (28 dB), the receive-to-transmit antenna isolation (table 4, column 8), and the receiving antenna deficiency (table 3, column 6). The total attenuation, added to the atmospheric noise level at the receiving subsystem input, will give the allowable level of noise at the transmitter output at 2½% off the channel frequency. These values are given in table 6, column 7.

TABLE 6. TRANSMITTER BROADBAND NOISE LIMITS (2½% FROM CHANNEL FREQUENCY).

(Col. 1) Freq, MHz	(2) Cplr, dB	(3) Ant Isolation, dB	(4) Rcvr Ant Def., dB	(5) Total Atten, dB	(6) Atmos Noise, Rcvr Subsys Input, dBm	(7) Level at Xmtr Output, dBm
2	28	0(-24)	26	54	-113	-59
4	28	0(-11)	20	48	-115	-67
6	28	0(-4)	17	45	-117	-72
8	28	0	15	43	-118	-75
10	28	4	13	45	-119	-74
12	28	8	11	47	-119	-72
15	28	12	9	49	-120	-71
20	28	17	7	52	-121	-69
25	28	21	5	54	-122	-68
30	28	24	4	56	-123	-67

A correction factor can be applied to these values should definite, rather than derived, values of antenna isolation be given. The same limits would apply for a 5-kW rated transmitter, unless an improved transmitting coupler or a higher value of antenna isolation were achieved.

(8) TRANSMITTER-GENERATED INTERMODULATION (TABLE 7)

The adverse effect of transmitter-generated intermodulation products (out-of-channel type) on the reception capability of the receiving subsystem can be limited by specifying an acceptable intermodulation power level at the receiving subsystem input. The intermodulation power level at this point must be no greater than the atmospheric noise power at the same point. Intermodulation type interference is not as serious as that due to broadband noise. It is a discrete-frequency phenomenon, rather than occurring over a band of frequencies as does transmitter broadband noise, and depends on a combination of two or more frequencies falling upon a third frequency.

Consideration will be given only to the third-order intermodulation signal at the F_1 transmitter output terminals generated in the power amplifier of the F_1 transmitter at the frequency $2F_1 - F_2$ under the induced power from the F_2 transmitter. F_2 is 5% in frequency above F_1, since 5% frequency separation between transmitters is the design goal. ($2F_1 - F_2$

represents the worst case because it is only 5% below F_1; $2F_2 - F_1$ is 10% above F_1, and will be attenuated by 12 dB more than is $2F_1 - F_2$ by the transmitting multicoupler.)

TABLE 7. TRANSMITTER THIRD-ORDER INTERMODULATION.

(Col. 1) Freq F_1, MHz	(2) Freq F_2 ($1.05 F_1$), MHz	(3) Freq $2F_1$-F_2, MHz	(4) Rcvr Ant Def., dB	(5) Ant Isolation, dB	(6) Xmtr Cplr at $2F_1$-F_2, dB	(7) Total Atten, dB	(8) Noise Level, Rcvr Subsys dBm	(9) Intermod Level at Xmtr F_1, dBm
2	2.10	1.90	26	0(-24)	40	66	-113	-47
4	4.20	3.80	20	0(-11)	40	60	-115	-55
6	6.30	5.70	17	0(-4)	40	57	-117	-60
8	8.40	7.60	15	0	40	55	-118	-63
10	10.50	9.50	13	4	40	57	-119	-62
12	12.60	11.40	11	8	40	59	-119	-60
15	15.75	14.25	9	12	40	61	-120	-59
20	21.00	19.00	7	17	40	64	-121	-57
25	26.25	23.75	5	21	40	66	-122	-56
30	31.50	28.50	4	24	40	68	-123	-55

The power of transmitter F_2 appearing at the transmitter F_1 output terminals will be reduced by 40 dB because of rejection contributed by the F_1 section of the transmitting multicoupler. A conversion loss estimated at 20 dB takes place in the intermodulation process which converts the combination of the F_1 and F_2 power to the frequency $2F_1 - F_2$. However, this figure is not needed in the calculations. The total attenuation to the third-order intermodulation frequency $2F_1 - F_2$ is the sum of the receiving antenna deficiency (table 3, column 6), the receive-to-transmit antenna isolation (table 4, column 8), and the transmitting multicoupler rejection (40 dB) at a frequency 5% below the F_1 frequency. The atmospheric noise level at the receiving subsystem input is given in table 7, column 8 (from table 3, column 4). The total attenuation (table 7, column 7) is added to the atmospheric noise level to obtain the maximum permissible intermodulation product $2F_1 - F_2$ level measured at the transmitter F_1 output terminals.

Should antenna isolation values be specified, rather than calculated, a correction factor may be applied.

(9) TRANSMITTER HARMONICS (TABLE 8)

The transmitting multicoupler minimum rejection will be assumed to be 60 dB at the harmonic frequencies. This value is probably somewhat conservative for the average case. The analysis is similar to that for transmitter-generated intermodulation products, except that now the transmitting multicoupler rejection is 60 dB rather than 40 dB. Columns 8 and 9 of table 8 show the permissible harmonic levels at the transmitter output terminals for interference level equal to the atmospheric noise level at the receiving subsystem input.

TABLE 8. HARMONIC LEVELS AT TRANSMITTER OUTPUT.

(Col. 1) Freq F_0, MHz	(2) Freq $2F_0$, MHz	(3) Freq $3F_0$, MHz	(4) Atten at $2F_0$, dB	(5) Atten at $3F_0$, dB	(6) Noise Level, Rcvr Subsys at $2F_0$ dBm	(7) Noise Level, Rcvr Subsys at $3F_0$ dBm	(8) $2F_0$ at Xmtr, dBm	(9) $3F_0$ at Xmtr, dBm
2	4	6	80	77	-115	-117	-35	-40
4	8	12	75	79	-118	-119	-43	-40
6	12	18	79	83	-119	-121	-40	-39
8	16	24	82	86	-120	-122	-38	-36
10	20	30	84	88	-121	-123	-37	-35
12	24		86		-122		-36	
15	30		88		-123		-35	

COMMON TRANSMITTING AND RECEIVING ANTENNA: TRANSCEIVER OPERATION

(1) GENERAL

When a single antenna is used for transmitting and receiving simultaneously, a transceiver frequently is used. Several transceivers may be multicoupled onto one antenna by using transmitting-type multicouplers, but no receiving couplers, with a transmit/receive relay associated with each transceiver.

The analyses are similar to those presented in the separate-transmit/receive-antenna case. However, there are differences due to three major deviations in circuit arrangement. Since a single antenna is used for both transmitting and receiving, and a transmitting antenna must operate at as high an efficiency as possible, the receiving antenna deficiency does not exist and can no longer be used as a receiving protection factor. There is now no space isolation between transmitting and receiving antennas – they are the same antenna. Also, a receiving multicoupler normally is not used, a channel of the transmitting multicoupler performing this function.

(2) DECOUPLING NETWORK (TABLE 9)

The receiving antenna deficiency and the receiving multicoupler on-channel insertion loss, both of which no longer exist in the transceiver arrangement, can be replaced by a fixed decoupling network having the attenuation-versus-frequency characteristic derived in table 9. If this is done, the basic design assumption that atmospheric noise and receiver noise shall be equal at the receiver subsystem input is preserved. This achieves a 3-dB impairment of usable receiving system sensitivity with maximum resistance to local interference. The decoupling network is interposed between the receiver input terminals and the connection to the transmitting multicoupler channel through the transmit/receive relay. In the analysis, it is considered as part of the receiving subsystem.

TABLE 9. CHARACTERISTICS OF FIXED DECOUPLING NETWORK.

(Col. 1) Freq, MHz	(2) Ant Def., dB	(3) Rcvr Cplr On-Channel Loss, dB	(4) Total Loss Needed, dB	(5) Xmtr Cplr On-Channel Loss, dB	(6) Decoupling Network Loss, dB
2	26	14	40	2	38
4	20	12	32	2	30
6	17	10	27	2	25
8	15	9	24	2	22
10	13	8	21	2	19
12	11	8	19	2	17
15	9	7	16	2	14
20	7	6	13	2	11
25	5	5	10	2	8
30	4	4	8	2	6

(3) CROSS MODULATION (TABLE 10)

In a transceiver arrangement, the transmitter and the receiver operate alternately on the same frequency. Since the design goal is 5% minimum separation for transmitting frequencies, this must hold for transmitter-to-receiver frequencies as well, rather than the 2½% used in the separate-antenna case. The receiver will probably have a three-pole front end. The assumed cross modulation power limit at the receiver input increases by 18 dB as the minimum frequency separation is doubled (6 dB per pole per octave). Therefore, the limit at the receiver input is now 18 dBm rather than the 0 dBm assumed in the separate-antenna case.

With a transmitter rated power output of 1 kW rms (+60 dBm), and allowing for a 2-dB loss in the transmitting coupler, the total attenuation required to reduce the interfering power down to the permissible maximum at the receiver input is +58 dBm - 18 dBm, or 40 dB. The attenuation available to control this interference is the sum of the fixed decoupling network attenuation and the attenuation due to the multicoupler channel being used for receiving, which is tuned 5% away from the transmitting frequency and, hence, has an attenuation of 40 dB. Column 5 of table 10 shows the total attenuation required, column 8 the total attenuation available, and column 9 the excess attenuation above requirements.

In this case, the excess attenuation above requirements is just equal to the loss of the decoupling network. This results from the particular figures used and would not hold in the general case.

TABLE 10. CROSS MODULATION ANALYSIS (TRANSCEIVER CASE).

(Col. 1) Freq, MHz	(2) Xmtr Output, dBm	(3) Cplr On-Channel Loss, dB	(4) Cross Mod Limit at Rcvr, dBm	(5) Total Atten Needed, dB	(6) Atten Fixed Net, dB	(7) Atten Cplr at 5%, dB	(8) Total Atten, dB	(9) Excess Over Reqd, dB
2	+60	2	+18	40	38	40	78	38
4	60	2	18	40	30	40	70	30
6	60	2	8	40	25	40	65	25
8	60	2	18	40	22	40	62	22
10	60	2	18	40	19	40	59	19
12	60	2	18	40	17	40	57	17
15	60	2	18	40	14	40	54	14
20	60	2	18	40	11	40	51	11
25	60	2	18	40	8	40	48	8
30	60	2	18	40	6	40	46	6

(4) TRANSMITTER-GENERATED INTERMODULATION (TABLE 11)

The basic requirement is that the level of the transmitter-generated third-order intermodulation products be equal to or below the atmospheric noise level at the receiving subsystem input, now the input to the fixed decoupling network. With two transmitters operating at frequencies F_1 and F_2, which are 5% separated in frequency, the third-order intermodulation product $2F_1 - F_2$ on the low side will be 5% below the lower F_1 of the two transmitting frequencies. The $2F_1 - F_2$ frequency will be the nearest receiver frequency to be protected. The intermodulation product on this frequency will be attenuated 40 dB by the selectivity of the transmit coupler channel associated with F_1 and further attenuated 2 dB by the on-channel insertion loss of the transmit coupler ~~channel~~ associated with the receiver.

TABLE 11. TRANSMITTER-GENERATED INTERMODULATION (TRANSCEIVER CASE – THIRD-ORDER PRODUCTS).

(Col. 1) Freq F_1, MHz	(2) Freq F_2, MHz	(3) Freq $2F_1 - F_2$, MHz	(4) Atmos Noise Rcvr Subsys, dBm	(5) Cplr Atten at F_1, dB	(6) Cplr Loss at $2F_1 - F_2$, dB	(7) Total Atten dB	(8) Intermod Level, dBm
2	2.10	1.90	-87	40	2	42	-45
4	4.20	3.80	-95	40	2	42	-53
6	6.30	5.70	-100	40	2	42	-58
8	8.40	7.60	-103	40	2	42	-61
10	10.50	9.50	-106	40	2	42	-64
12	12.60	11.40	-108	40	2	42	-66
15	15.75	14.25	-111	40	2	42	-69
20	21.00	19.00	-114	40	2	42	-72
25	26.25	23.75	-117	40	2	42	-75
30	31.50	28.50	-119	40	2	42	-77

Column 8 of table 11 displays the permissible third-order intermodulation level measured at the transmitter F_1 output terminals at the intermodulation product frequencies listed in column 3. Higher-order intermodulation products probably will be of lesser magnitude. Second-order products will be far removed in frequency from the receiving frequencies in use, and substantially attenuated.

(5) TRANSMITTER BROADBAND NOISE (TABLE 12)

The levels derived for the permissible levels for the third-order intermodulation products also hold for the transmitter broadband noise limits at a frequency 5% from the transmitter frequency. They are derived in a similar manner.

Table 12 presents the calculations and the results. The broadband noise level limit listed in column 6 is that measured at the transmitter output terminals at a frequency 5% above or below the transmitter operating frequency.

TABLE 12. TRANSMITTER BROADBAND NOISE (TRANSCEIVER CASE).

(Col. 1) Freq F_0, MHz	(2) Atmos Noise Rcvr Subsys, dBm	(3) Cplr Atten at $F_0 \pm 5\%$, dB	(4) Cplr On-Channel Insertion Loss, dB	(5) Total Atten, dB	(6) Noise Level at Xmtr, dBm
2	-87	40	2	42	-45
4	-95	40	2	42	-53
6	-100	40	2	42	-58
8	-103	40	2	42	-61
10	-106	40	2	42	-64
12	-108	40	2	42	-66
15	-111	40	2	42	-69
20	-114	40	2	42	-72
25	-117	40	2	42	-75
30	-119	40	2	42	-77

(6) SECOND- AND THIRD-HARMONIC LEVELS (TABLE 13)

Since the transmitting multicoupler maximum attenuation that can be counted on probably does not much exceed 60 dB, the permissible second- and third-harmonic levels at the transmitter output terminals are only 20 dB higher than the intermodulation product or the broadband noise levels at the pertinent frequencies.

Columns 8 and 9 of table 13 list the permissible harmonic levels at the transmitter output terminals of the transceiver.

TABLE 13. HARMONIC LEVELS AT TRANSCEIVER OUTPUT.

(Col. 1) Freq F_0, MHz	(2) Freq $2F_0$, MHz	(3) Freq $3F_0$, MHz	(4) Atten at $2F_0$, dB	(5) Atten at $3F_0$, dB	(6) Noise Level Rcvr Subsys at $2F_0$ dBm	(7) Noise Level Rcvr Subsys at $3F_0$ dBm	(8) $2F_0$ at Xmtr, dBm	(9) $3F_0$ at Xmtr, dBm
2	4	6	62	62	-95	-100	-33	-38
4	8	12	62	62	-103	-108	-41	-46
6	12	18	62	62	-108	-113	-46	-51
8	16	24	62	62	-112	-117	-50	-55
10	20	30	62	62	-114	-119	-52	-57
12	24		62		-117		-55	
15	30		62		-119		-57	

(7) LIABILITY TO BURNOUT DAMAGE

The fixed decoupling network added in the receiving subsystem must be designed to withstand without damage the power from transceivers operating in the transmission mode on other channels of the transmitting multicoupler. The nearest transmitting frequency can be as close as 5% to the receiving channel frequency. At this frequency separation the coupler channel operating in the receiving mode will provide 42-dB rejection (40 dB due to selectivity and 2 dB due to losses). The transmitter output level is +60 dBm; thus, the decoupling network must be designed to withstand a power level of +18 dBm, or 0.063 watt.

The receiver input circuit will be protected by the additional attenuation of the fixed decoupling network, varying from 38 dB to 6 dB with frequency. There should be no problem of inadequate protection for the receiver.

COMMON ANTENNA FOR TRANSMITTING AND RECEIVING VIA SEPARATE TRANSMITTERS AND RECEIVERS

(1) GENERAL

In this arrangement a common antenna is used for both transmitting and receiving, but separate transmitters and receivers are used instead of a transceiver. There is no transmit/receive relay and both transmitting and receiving multicouplers are retained. Now the transmitting frequency and the receiving frequency are no longer tied together, as they were when the transceiver was used. The minimum transmit-to-transmit frequency separation remains at 5%, but the minimum transmit-to-receive frequency separation is now 2½%. Also, both antenna deficiency and transmit-to-receive antenna isolation no longer exist for this case. Figure 5 displays the arrangements.

(2) DECOUPLING NETWORK DESIGN (TABLE 14)

As in the separate-antenna case, the design philosophy is to match the atmospheric noise level and the receiver noise level at the receiving multi-coupler input. In the separate-antenna case this was achieved by the inclusion of an antenna deficiency factor in the design. Since the antenna now is used for transmitting also and must have high efficiency, this approach is not possible. A fixed decoupling network is provided having suitable attenuation-versus-frequency characteristics. This decoupling network will have exactly the same attenuation-versus-frequency characteristics as the antenna deficiency factor derived in table 3, column 6. Table 14 repeats the results for convenience in reference. Notice that this decoupling network is not identical with that designed for the transceiver case.

TABLE 14. CHARACTERISTICS OF FIXED DECOUPLING NETWORK.

Freq, MHz	Atten, dB	Freq, MHz	Atten, dB
2	26	12	11
4	20	15	9
6	17	20	7
8	15	25	5
10	13	30	4

(3) RECEIVER CROSS MODULATION (TABLE 15)

The gap between the receiver cross modulation performance assumed (0 dBm) and the transmitter output power minus coupler loss (60 dBm - 2 dB) is 58 dB. The total attenuation available to protect the receiver consists of the decoupling network attenuation (table 14) and the receiving multi-coupler attenuation at a frequency 2½% off channel (table 1, column 3). This attenuation is summed in column 4 and compared with the needed attenuation, column 5, to obtain an excess or deficiency value.

At frequencies above 8 MHz the needed attenuation is not available. There are two possible remedies. One is to relax the transmit-to-receive frequency separation requirements above 8 MHz sufficiently so that the increased attenuation of the receiving coupler will make up the attenuation deficit. This will require a 5% frequency separation at 30 MHz, and a lesser separation as the channel frequency is lowered toward 8 MHz. The second possible remedy involves adding a tunable network to track in frequency the receiving coupler and receiver, and having the attenuation characteristics given in column 6. If the second approach is used, the fixed decoupling network loss characteristic should be diminished by an amount equivalent to the on-channel loss of the tunable network added.

TABLE 15. RECEIVER CROSS MODULATION CHARACTERISTICS.

(Col. 1) Freq, MHz	(2) Decplr Net Atten, dB	(3) Rcvr Cplr Atten, dB	(4) Total Atten, dB	(5) Reqd Atten, dB	(6) Additional Atten Needed, dB
2	26	56	82	58	-24
4	20	49	69	58	-11
6	17	45	62	58	-4
8	15	43	58	58	0
10	13	41	54	58	4
12	11	39	50	58	8
15	9	37	46	58	12
20	7	34	41	58	17
25	5	32	37	58	21
30	4	30	34	58	24

(4) TRANSMITTER-GENERATED INTERMODULATION (TABLE 16)

The basic intermodulation requirement still is that the transmitter-generated third-order intermodulation products at the receiver subsystem input shall not exceed the quasi-minimum atmospheric noise level at that point. The receiver subsystem includes a fixed decoupling network, but it is not the same network as in the transceiver case. Otherwise, the analysis proceeds as in the transceiver case with only slightly different values. Table 16 displays the calculations and the results.

TABLE 16. TRANSMITTER-GENERATED INTERMODULATION (COMMON-T/R-ANTENNA CASE – THIRD-ORDER PRODUCTS).

(Col. 1) Freq F_1, MHz	(2) Freq F_2, MHz	(3) Freq $2F_1$-F_2, MHz	(4) Atmos Noise Rcvr Subsys, dBm	(5) Xmtr Cplr Atten 5%, dB	(6) IM Level at Xmtr, dBm
2	2.10	1.90	-87	40	-47
4	4.20	3.80	-95	40	-55
6	6.30	5.70	-100	40	-60
8	8.40	7.60	-103	40	-63
10	10.50	9.50	-106	40	-66
12	12.60	11.40	-108	40	-68
15	15.75	14.25	-111	40	-71
20	21.00	19.00	-114	40	-74
25	25.25	23.75	-117	40	-77
30	31.50	28.50	-119	40	-79

(5) TRANSMITTER BROADBAND NOISE (TABLE 17)

In this arrangement, the minimum frequency separation between transmitting and receiving channels is 2½%, rather than the 5% that applies in the transceiver case. Hence, the transmitter coupler attenuation is 28 dB, rather than 40 dB.

Table 17 presents the broadband noise limits at the transmitter output terminals for frequencies 2½% from the transmitter operating channel.

TABLE 17. TRANSMITTER BROADBAND NOISE (COMMON-T/R-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Atmos Noise At Rcvr Subsys, dBm	(3) Xmtr Cplr Atten, 2½%, dB	(4) Broadband Noise at Xmtr, dBm
2	-87	28	-59
4	-95	28	-67
6	-100	28	-72
8	-103	28	-75
10	-106	28	-78
12	-108	28	-80
15	-111	28	-83
20	-114	28	-86
25	-117	28	-89
30	-119	28	-91

(6) SECOND- AND THIRD-HARMONIC POWER LEVELS (TABLE 18)

The permissible second- and third-harmonic power levels at the transmitter output terminals will be 20 dB greater than for the intermodulation product level, because of the 20-dB greater attenuation assumed for the transmitting multicoupler at these frequencies – 60 dB rather than 40 dB. This is a conservative estimate.

Table 18 presents the results of these calculations.

TABLE 18. HARMONIC LEVELS AT TRANSMITTER OUTPUT (COMMON-T/R-ANTENNA CASE).

(Col. 1) Freq F_0, MHz	(2) Freq $2F_0$, MHz	(3) Freq $3F_0$, MHz	(4) Atten at $2F_0$, dB	(5) Atten at $3F_0$, dB	(6) Noise Level at $2F_0$, dBm	(7) Rcvr Subsys at $3F_0$, dBm	(8) $2F_0$ at Xmtr, dBm	(9) $3F_0$ at Xmtr, dBm
2	4	6	60	60	-95	-100	-35	-40
4	8	12	60	60	-103	-108	-43	-48
6	12	18	60	60	-108	-113	-48	-53
8	16	24	60	60	-112	-117	-52	-57
10	20	30	60	60	-114	-119	-54	-59
12	24		60		-117		-57	
15	30		60		-119		-59	

(7) LIABILITY TO BURNOUT DAMAGE (TABLE 19)

Since the transmitters and receivers are connected to a common antenna with no transmit-to-receive antenna isolation, protection of the receiving subsystem is needed. Assume that up to eight 1-kW transmitters might be connected to one antenna through a transmitting multicoupler. This would represent a possible power level of 8 kW, or 69 dBm, if all transmitters operated simultaneously – a somewhat unlikely circumstance. The fixed decoupling network must be designed to withstand the voltages associated with this power level.

The receiving multicoupler will also require redesign to increase its ability to withstand exposure to higher power. The level at the receiving multicoupler input will be reduced by the attenuation of the fixed decoupling network. Since the decoupling network basically is nonselective in frequency, the combined power level of eight transmitters must still be considered. Column 6 of table 19 shows power levels at the receiving multicoupler input of 20 to 1600 watts, depending on frequency.

The receiver itself is protected by the selectivity of the receiving multicoupler, and, hence, the power of only two transmitters, those at 2½% above and below the receiving frequency, really impinge on the receiver. The next nearest frequencies are at least 7½% away and contribute little. Column 1 of table 19 shows that the power levels at the receiver input are below 1 watt at all frequencies.

TABLE 19. POWER LEVEL EXPOSURES OF RECEIVING SUBSYSTEM (COMMON-T/R-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Xmtr Level, dBm	(3) Level at Decplr Network, dBm	(4) Atten of Decplr Network, dB	(5) Level at Rcvr Cplr, dBm	(6) Level at Rcvr Cplr, W	(7) Exposure of Rcvr (2 Xmtrs), dBm	(8) Rcvr Cplr Atten, 2½%, dB	(9) Level at Rcvr, dBm	(10) Level at Rcvr, W
2	+69	+69	26	+43	20	+37	56	-19	0.000012
4	+69	+69	20	+49	80	+43	49	-6	0.00025
6	+69	+69	17	+52	180	+46	45	+1	0.0013
8	+69	+69	15	+54	250	+48	43	+5	0.0032
10	+69	+69	13	+56	400	+50	41	+9	0.0079
12	+69	+69	11	+58	630	+52	39	+13	0.020
15	+66	+66	9	+51	500	+54	37	+17	0.050
20	+66	+66	7	+59	794	+56	34	+22	0.16
25	+66	+66	5	+61	1260	+58	32	+26	0.40
30	+66	+66	4	+62	1585	+59	30	+29	0.79

SUMMATION OF REQUIREMENTS

In table 20 the requirements for the various possible system arrangements are summarized for ease of comparison and for the determination of the most critical parameter values. These requirements are based on reasonable assumed values of the element characteristics.

In the succeeding sections actual values for representative current equipments are introduced and comparisons with the reference system made to determine current equipment deficiencies in meeting the critical requirements. Then various possible modifications or improvements needed are discussed.

The AN/URT-23(V) Radio Transmitter and the R-1051-D/URR Radio Receiver will be considered representative of currently used equipments.

TABLE 20. SUMMARY OF REQUIREMENTS.

(Based on Equality of Atmospheric and Receiver Noise at Receiving Subsystem Input)

	Freq, MHz 2	4	6	8	10	12	15	20	25	30
Receiving Antenna Deficiency, dB below ideal receiving antenna										
Separate-antenna case	26	20	17	15	13	11	9	7	5	4
Transceiver case	N/A									
Common-T/R-antenna case	N/A									
T/R Antenna Isolation, dB										
Separate-antenna case	-24	-11	-4	0	4	8	12	17	21	24
Transceiver case	N/A									
Common-T/R-antenna case	N/A									
Decoupling Network, dB										
Separate-antenna case	N/A									
Transceiver case	38	30	25	22	19	17	14	11	8	6
Common-T/R-antenna case	26	20	17	15	13	11	9	7	5	4
Broadband Noise, Transmitter, dBm at transmitter output										
Separate-antenna case, 2½%	-59	-67	-72	-75	-74	-72	-71	-69	-68	-67
Transceiver case, 5%	-45	-53	-58	-61	-64	-66	-69	-72	-75	-77
Common-T/R-antenna case, 2½%	-59	-67	-72	-75	-78	-80	-83	-86	-89	-91
Cross Modualtion, dB excess attenuation margin										
Separate-antenna case	T/R antenna isolation gives 0-dBm level									
Transceiver case	38	30	25	22	19	17	14	11	8	6
Common-T/R-antenna case	24	11	4	0	-4	-8	-12	-17	-21	-24
Intermodulation, Transmitter, dBm at transmitter output										
Separate-antenna case	-47	-55	-60	-63	-62	-60	-59	-57	-56	-55
Transceiver case	-45	-53	-58	-61	-64	-66	-69	-72	-75	-77
Common-T/R-antenna case	-47	-55	-60	-63	-66	-68	-71	-74	-77	-79

TABLE 20. (Continued)

	Freq, MHz									
	2	4	6	8	10	12	15	20	25	30
Harmonics, dBm at transmitter output										
Separate-antenna case										
2nd	-35	-43	-40	-38	-37	-36	-35			
3rd	-40	-40	-39	-36	-35					
Transceiver case										
2nd	-33	-41	-46	-50	-52	-55	-57			
3rd	-38	-46	-51	-55	-57					
Common-T/R-antenna case										
2nd	-35	-43	-48	-52	-54	-57	-59			
3rd	-40	-48	-53	-57	-59					
Protection Requirements, level at input terminals										
Fixed Decoupling Network Input, W										
Separate-antenna case	N/A									
Transceiver case	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
Common-T/R-antenna case	8kW	8kW	8kW	8kW	8kW		4kW	4kW	4kW	4kW
Receiving Multicoupler Input, W										
Separate-antenna case	1.58	6.3	12.6	20.0	12.6	7.9	5.0	2.0	1.6	1.0
Transceiver case	N/A									
Common-T/R-antenna case	20	80	180	250	400	630	501	794	1260	1585
Receiver Input, W										
Separate-antenna case	0.063	0.40	1.26	2.51	2.00	1.26	1.00	0.50	0.50	0.40
Transceiver case	Negligible									
Common-T/R-antenna case	0.000012	0.00025	0.0013	0.0032	0.0079	0.020	0.050	0.16	0.40	0.79

COMPARISON OF REQUIREMENTS AND CHARACTERISTICS OF CURRENT EQUIPMENTS

In this section a comparison is made between the reference system, its characteristics, and its derived requirements, and a system using the actual characteristics of currently installed equipments. Thus, it will be determined to what extent current equipments fail to meet the reference system requirements. In some cases there will be considerable divergence between the requirements and current achievement. Then the equipment improvements or system modifications needed to overcome the shortcomings will be discussed.

Equipments representative of current practice include the R-1051-D/URR Radio Receiver, the AN/SRA-38/39/40/49 Receiving Antenna Couplers, the AN/SRA-56/57/58 Transmitting Antenna Couplers, and the AN/URT-23(V) Radio Transmitter. Antenna system characteristics are discussed in a subsequent paragraph.

SEPARATE-ANTENNA CASE

(1) RECEIVER NOISE FIGURE

The noise figure of the R-1051 D/URR Radio Receiver is about 12 dB over a major portion of its tuning range, with perhaps a maximum of about 16 dB at the extreme upper end of the band. The 12-dB figure was used in the reference system analysis.

There is little to be gained by attempting to reduce this noise figure, particularly in the lower portion of the frequency band where the quasi-minimum atmospheric noise level is relatively high. If the receiver noise figure can be reduced somewhat without loss of receiver front end selectivity, the difference might be allocated to an increase in the receiving multicoupler selectivity and on-channel loss or to an increase in the receiving antenna deficiency. Either modification would reduce the susceptibility of the receiving subsystem to interference from local transmissions.

(2) ANTENNA SYSTEM CHARACTERISTICS (TABLE 21)

The analysis of the reference system has derived the attenuation-versus-frequency characteristics needed for the receiving antenna deficiency and for the transmit-to-receive antenna isolation to provide satisfactory hf communication system performance. The question is -- can these characteristics be realized on an actual ship?

The antenna system of DLG 26 was studied by measurement on a 1/48-scale ship model. The isolation between 10 selected antenna combinations having physical separations between 22 feet and 527 feet was measured. While there was considerable scatter in the results, the lowest isolation values measured were sufficient to meet the derived isolation requirements; and the average isolation values, expressed in dB, were about twice the requirement.

This leads to the conclusion that an antenna system such as that installed on DLG 26 is capable of meeting the reference system requirements without substantial modification. Table 21 shows the transmitting-to-receiving antenna isolation considered as representative of current practice. The tabulated values are somewhat greater than the lowest isolation values observed, but are much less than the average isolation values. Antenna deficiency values which result from matching quasi-minimum atmospheric noise to the receiver internal noise at the receiving subsystem input are included. They are the same values as given in table 3, column 6.

TABLE 21. ANTENNA SYSTEM CHARACTERISTICS (SEPARATE-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Antenna T/R Isolation, dB	(3) Antenna Def., dB
2	10	26
4	13	20
6	16	17
8	19	15
10	22	13
12	25	11
15	28	9
20	32	7
25	34	5
30	36	4

(3) RECEIVER CROSS MODULATION PERFORMANCE (TABLE 22)

The average cross modulation performance of the R-1051-D/URR receiver is about 10 dB poorer than that assumed for the reference system – -10 dBm for the R-1051 versus 0 dBm for the reference system. These figures are for the permissible interfering power levels at the receiver input terminals at frequencies 2½% from the on-channel frequency. Desensitization and receiver intermodulation products occur at approximately the same power levels as those at which cross modulation occurs.

For the case of separate transmitting and receiving antennas, table 22 presents the analysis for receiver cross modulation using the antenna system characteristics listed in table 21. With the antenna characteristics representative of current ship installations, the R-1051-D/URR receiver cross modulation performance is better than required by the amount shown in table 22, column 9.

TABLE 22. RECEIVER CROSS MODULATION (SEPARATE-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Xmtr Output, dBm	(3) Xmtr Cplr Loss, dB	(4) Rcvr Cplr Atten 2½%, dB	(5) Ant Def., dB	(6) Ant Isolation, dB	(7) Total Atten, dB	(8) Atten Needed, dB	(9) Excess Over Reqd, dB
2	+60	2	56	26	10	94	70	24
4	+60	2	49	20	13	84	70	14
6	+60	2	45	17	16	80	70	10
8	+60	2	43	15	19	79	70	9
10	+60	2	41	13	22	78	70	8
12	+60	2	39	11	25	77	70	7
15	+60	2	37	9	28	76	70	6
20	+60	2	34	7	32	75	70	5
25	+60	2	32	5	34	73	70	3
30	+60	2	30	4	36	72	70	2

(4) RECEIVER INTERMODULATION (TABLE 23)

Receiver intermodulation requires the presence o. two or more strong signals at the receiver input. Normally, the minimum frequency separation between transmitting frequencies will be 5%. Thus, for a third-order intermodulation product the two strong signals will be 5% and 10% from the frequency to which the receiver is tuned.

Table 23 shows the calculations for the level of the stronger of two local signals at the receiver input. The signal is attenuated by the transmit-to-receive antenna isolation, the receiving antenna deficiency, and the receiving multicoupler selectivity at 5% from the transmitting frequency. The signal at 10% frequency separation will be 24 dB less.

The power level is so low at the receiver input that no interference is expected from this source. While no measurements were available on the intermodulation performance of the R-1051 receiver, measurements on similar receivers indicate permissible levels of about -22 dBm at the receiver input terminals.

TABLE 23. RECEIVER INTERMODULATION (SEPARATE-ANTENNA CASE).

(Col. 1) Freq. MHz	(2) Ant Isolation, dB	(3) Ant Def., dB	(4) Rcvr Cplr Atten, 5%, dB	(5) Xmtr Cplr Loss, dB	(6) Total Atten, dB	(7)* Xmtr Output, dBm	(8) Level at Rcvr, dBm
2	10	26	80	2	118	+60	-58
4	13	20	73	2	108	+60	-48
6	16	17	69	2	104	+60	-44
8	19	15	67	2	103	+60	-43
10	22	13	65	2	102	+60	-42
12	25	11	63	2	101	+60	-41
15	28	9	61	2	100	+60	-40
20	32	7	58	2	99	+60	-39
25	34	5	56	2	97	+60	-37
30	36	4	54	2	96	+60	-36

(5) LIABILITY TO BURNOUT DAMAGE (TABLE 24)

Should the receiving frequency coincide with a local transmitting frequency during tuning operations, there might be a problem from exposure of the receiving multicoupler or receiver to excessive power levels. During normal operations, where a minimum of 2½% frequency separation exists between transmitting and receiving frequencies, the multicoupler input is still exposed to the same power levels, but the receiver input is further protected by the receiving multicoupler selectivity.

Table 24 shows the analysis for the case in which the transmitting and the receiving frequencies coincide. It is clear that there is no excessive exposure, all levels being well below 1 watt. Should a 5-kW rated transmitter be used, these levels would increase by 7 dB.

TABLE 24. RECEIVING SUBSYSTEM EXPOSURE LEVELS (SEPARATE-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Rcvr Ant Def., dB	(3) Ant Isolation, dB	(4) Xmtr Cplr Loss, dB	(5) Total Loss, dB	(6) Xmtr Level, dBm	(7) Level at Rcvr Cplr, dBm	(8) W	(9) Rcvr Cplr Loss, dB	(10) Level at Rcvr, dBm	(11) W
2	26	10	2	38	+60	+22	0.158	14	+8	0.006
4	20	13	2	35	+60	+25	0.316	12	+13	0.020
6	17	16	2	35	+60	+25	0.316	10	+15	0.032
8	15	19	2	36	+60	+24	0.251	9	+15	0.032
10	13	22	2	37	+60	+23	0.200	8	+15	0.032
12	11	25	2	38	+60	+22	0.158	8	+14	0.025
15	9	28	2	39	+60	+21	0.126	7	+14	0.025
20	7	32	2	41	+60	+19	0.079	6	+13	0.020
25	5	34	2	41	+60	+19	0.079	5	+14	0.025
30	4	36	2	42	+60	+18	0.063	4	+14	0.025

(6) TRANSMITTER BROADBAND NOISE (TABLE 25)

Broadband noise output is one aspect in which current-type transmitters are clearly deficient in meeting the requirements established by the reference system. While the measured data available on the broadband noise output of the URT-23 transmitter are incomplete and show considerable scatter, it is evident that the broadband noise output is excessive. In table 25, columns 2 and 3 show estimated values of broadband noise in a 3-kHz bandwidth at the URT-23 transmitter output terminals at frequencies 2½% and 5% from the operating frequency. The transmitter was keyed but no modulation applied. Columns 8 and 9 show the total attenuation offered to the broadband noise at 2½% and 5% frequency separation, and columns 10 and 11 the corresponding levels at the receiving subsystem input. Column 12 shows the atmospheric noise level at that point. Columns 13 and 14 show the excess of transmitter broadband noise over the atmospheric noise for 2½% and 5% frequency separation.

The URT-23 transmitter requires an average reduction in broadband noise of 23 dB if the 2½% frequency separation is to be achieved. The alternative is to increase the minimum frequency separation to about 4%. This analysis holds only for the separate-antenna case. Other arrangements, such as the use of transceivers, will demand more severe restrictions.

TABLE 25. TRANSMITTER BROADBAND NOISE ANALYSIS (SEPARATE-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) URT-23 Noise 2½% dBm	(3) 5% dBm	(4) Xmtr Cplr Atten 2½% dB	(5) 5% dB	(6) Ant Isolation, dB	(7) Ant Def., dB	(8) Total Atten 2½% dB	(9) 5% dB	(10) Level at Rcvr Subsys 2½% dBm	(11) 5% dBm	(12) Atmos Noise Rcvr Subsys, dBm	(13) Excess Noise 2½% dB	(14) 5% dB
2	-22	-44	28	40	10	26	64	76	-86	-120	-113	+27	-7
4	-30	-52	28	40	13	20	61	73	-91	-125	-115	+24	-10
6	-34	-56	28	40	16	17	61	73	-95	-129	-117	+22	-12
8	-36	-58	28	40	19	15	62	74	-98	-132	-118	+20	-14
10	-37	-59	28	40	22	13	63	75	-100	-134	-119	+19	-15
12	-37	-60	28	40	25	11	64	76	-101	-136	-119	+18	-17
15	-36	-60	28	40	28	9	65	77	-101	-137	-120	+19	-17
20	-32	-58	28	40	32	7	67	79	-99	-137	-121	+22	-16
25	-28	-56	28	40	34	5	67	79	-95	-135	-122	+27	-13
30	-23	-52	28	40	36	4	68	80	-91	-132	-123	+32	-9

(7) TRANSMITTER INTERMODULATION OUTPUTS (TABLE 26)

The specification for the URT-23 transmitter requires that third-order intermodulation products be at least 35 dB below either tone of a two-tone test at full rated power output of 1 kW PEP. This requirement is equivalent to an intermodulation level of +19 dBm average. The specification, however, is for inband intermodulation with two equal tones spaced perhaps 1 kHz apart and does not represent accurately an out-of-band situation in which the two intermodulating signals are separated in frequency by 5% and are of unequal amplitudes.

Limited measurements have indicated that the intermodulation product level at the output of a combination of a URT-23 transmitter and a SRA-58 multicoupler for two frequencies separated 5% is about 55 dB above 1 microvolt, equivalent to -52 dBm at the multicoupler output or -12 dBm at the transmitter output terminals. There is some question as to whether the multicoupler was contributing to this level or whether it was entirely due to transmitter action as assumed.

Table 26 presents the transmitter intermodulation analysis for third-order products for the separate-antenna case. The level at the transmitter output (-12 dBm) is attenuated by the transmitting multicoupler, by the receiving antenna deficiency, and by the transmit-to-receive antenna isolation. The level at the receiving subsystem input is then compared with the atmospheric noise level at that point. The results show that the third-order intermodulation products are about 30 dB in excess of the atmospheric noise.

Unless the intermodulation performance of transmitters can be improved, it may be necessary by careful frequency selection to avoid the combinations of transmitting frequencies that will produce third-order intermodulation products which fall on receiving channels.

It should be noted that in a shipboard situation intermodulation products will be generated by nonlinear action in the antenna environment as well as in the transmitters; that is, in the topside rigging, cabling, and structures, for example, within the sphere of influence of the antennas. This phenomenon is extremely difficult to control. Third-order intermodulation product levels observed aboard the average ship are about 60 dB above 1 microvolt at the receiving antenna terminals, which is equivalent to about -27 dBm. With special attention to installation and maintenance procedures, it appears possible to reduce this level on the average by about 30 dB, or to a level of -57 dBm. This is just about equal to the level (-52 dBm) that the URT-23 transmitter achieves at the transmitting coupler output. Since these two effects fall upon exactly the same frequencies, it may do little good to improve substantially either one alone until the other can be brought under control.

TABLE 26. TRANSMITTER INTERMODULATION ANALYSIS (SEPARATE-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) IM at Xmtr Output, dBm	(3) Xmtr Cplr Atten, dB	(4) Rcvr Ant Def., dB	(5) T/R Ant Isolation, dB	(6) Total Atten, dB	(7) Level at Rcvr Subsys, dBm	(8) Atmos Noise Rcvr Subsys, dBm	(9) Excess IM, dB
2	-12	40	26	10	76	-88	-113	25
4	-12	40	20	13	73	-85	-115	30
6	-12	40	17	16	73	-85	-117	32
8	-12	40	15	19	74	-86	-118	32
10	-12	40	13	22	75	-87	-119	32
12	-12	40	11	25	76	-88	-119	31
15	-12	40	9	28	77	-89	-120	31
20	-12	40	7	32	79	-91	-121	30
25	-12	40	5	34	79	-91	-122	31
30	-12	40	4	36	80	-92	-123	31

(8) TRANSMITTER HARMONIC OUTPUTS (TABLE 27)

The specification for the URT-23 transmitter calls for a second-harmonic radiation down at least 45 dB from the 1-kW PEP rating of the transmitter and all other harmonics at least 55 dB down. This corresponds to harmonic power levels of +15 dBm and +5 dBm. These values are used, since measured values are not available.

Table 27 presents the analysis for the second-harmonic case. The analysis for the third harmonic is similar and gives values about 10 dB less. The minimum rejection of the transmitting multicoupler was assumed to be 60 dB at the harmonic frequencies – probably a somewhat conservative value for the average case. The second-harmonic level exceeds the atmospheric noise level at the receiver subsystem input by about 40 dB.

The most obvious remedy is to leave the transmitter harmonic frequencies unassigned for local receiving purposes. Since the interference is of a spot frequency nature, instead of extending over a band of frequencies as does broadband noise, this may be an acceptable solution.

TABLE 27. TRANSMITTER HARMONIC ANALYSIS (SEPARATE-ANTENNA CASE).

(Col. 1) Freq F_0, MHz	(2) Freq $2F_0$, MHz	(3) 2nd Hmnc at Xmtr, dBm	(4) Xmtr Cplr Atten, dB	(5) T/R Ant Isolation, dB	(6) Rcvr Ant Def., dB	(7) Total Atten, dB	(8) Level at Rcvr Subsys, dBm	(9) Atmos Noise, dBm	(10) Excess Above Noise, dB
2	4	+15	60	13	20	93	-78	-115	37
4	8	+15	60	19	15	94	-79	-118	39
6	12	+15	60	25	11	96	-81	-119	38
8	16	+15	60	29	9	98	-83	-120	37
10	20	+15	60	32	7	99	-84	-121	37
12	24	+15	60	34	5	99	-84	-122	38
15	30	+15	60	36	4	100	-85	-123	38

(Third-harmonic levels are about 10 dB less than these values)

TRANSCEIVER CASE

In the transceiver case the transmitting antenna is used also as a receiving antenna, and the transmitting multicoupler is used for receiving in place of a receiving multicoupler. There is now no space isolation between transmitting and receiving antennas, since a common antenna is used for these two functions. There is no receiving antenna deficiency, since an efficient transmitting antenna is used. The receiving antenna deficiency factor and the receiving multicoupler on-channel insertion loss are replaced by a fixed decoupling network which is inserted to match the atmospheric noise level to the receiver internal noise level. This network is specified in table 9.

(1) RECEIVER CROSS MODULATION (TABLE 28)

In a transceiver application the receiving frequency is tied to the transmitting frequency. Since the minimum separation between transmitting frequencies is 5%, this must also be the minimum separation between a receiving frequency and a transmitting frequency. The cross modulation power limit for the R-1051 receiver at 5% is +8 dBm, rather than the -10 dBm limit for 2½%.

Table 28 presents the analysis. Column 8 shows that the receiver cross modulation requirement is met except at the two highest frequencies.

(2) RECEIVER INTERMODULATION

The receiver intermodulation limit of the R-1051 receiver is the same as the cross modulation limit, or +8 dBm. The analysis is similar to that of the cross modulation case and the results are the same, so table 28 also holds for receiver intermodulation. The requirement is more than met, except at the two highest frequencies.

TABLE 28. RECEIVER CROSS MODULATION (TRANSCEIVER CASE).

(Col. 1) Freq, MHz	(2) Xcvr Output Power, dBm	(3) Xmtr Cplr On-Channel Loss, dB	(4) Xmtr Cplr (Rcvr) at 5%, dB	(5) Decplr Network Atten, dB	(6) Total Atten, dB	(7) CM Limit, dBm	(8) Excess Over Reqd, dB
2	+60	2	40	38	80	+8	28
4	+60	2	40	30	72	+8	20
6	+60	2	40	25	67	+8	15
8	+60	2	40	22	64	+8	12
10	+60	2	40	19	61	+8	9
12	+60	2	40	17	59	+8	7
15	+60	2	40	14	56	+8	4
20	+60	2	40	11	53	+8	1
25	+60	2	40	8	50	+8	-2
30	+60	2	40	6	48	+8	-4

(3) LIABILITY TO BURNOUT DAMAGE

The fixed decoupling network in the receiving subsystem must be designed to withstand the power from transceivers operating in the transmitting mode on other channels of the transmitting multicoupler. The nearest transmitting frequency can be as close as 5% to the receiving channel frequency. At this frequency separation the transmitting coupler channel operation in the receiving mode will provide 42 dB rejection – 40 dB due to selectivity and 2 dB due to losses. The transmitter output level is +60 dBm. Thus, the fixed decoupling network must withstand a power level of 60 dBm minus 42 dB, or +18 dBm, which is 0.063 watt.

The receiver input will be protected by the additional attenuation of the fixed decoupling network. There should be no problem of inadequate protection for the receiver.

(4) TRANSMITTER BROADBAND NOISE (TABLE 29)

In the transceiver case the minimum frequency separation between transmitting and receiving frequencies is 5%. The broadband noise of the transmitter at 5% from its operating frequency is attenuated by the transmitting multicoupler. The level is then compared with the atmospheric noise level at the receiving subsystem input.

Table 29 shows the calculations. The transmitter broadband noise exceeds the atmospheric noise by 3 to 27 dB. Unless the broadband noise of the transmitter can be reduced, this indicates that a greater than 5% frequency separation is required, particularly at the higher frequencies.

TABLE 29. TRANSMITTER BROADBAND NOISE (TRANSCEIVER CASE).

(Col. 1) Freq, MHz	(2) URT-23 Noise at 5%, dBm	(3) Xmtr Cplr Atten, dB	(4) Level at Rcvr Subsys, dBm	(5) Atmos Noise at Rcvr Subsys, dBm	(6) Excess BB Noise, dB
2	-44	40	-84	-87	+3
4	-52	40	-92	-95	+3
6	-56	40	-96	-100	+4
8	-58	40	-98	-103	+5
10	-59	40	-99	-106	+7
12	-60	40	-100	-108	+8
15	-60	40	-100	-111	+11
20	-58	40	-98	-114	+16
25	-56	40	-96	-117	+21
30	-52	40	-92	-119	+27

(5) TRANSMITTER INTERMODULATION OUTPUT (TABLE 30)

Table 30 presents the transmitter intermodulation analysis for third-order products for the transceiver case. The only attenuation is that provided by the transmitting multicoupler. The intermodulation product levels are 35 dB to 67 dB in excess of the atmospheric noise levels at the receiving subsystem input. Probably frequency selection will be necessary to avoid frequency combination that will produce third-order intermodulation products which fall on receiving channels. Fifth-order products may also cause some interference.

TABLE 30. TRANSMITTER INTERMODULATION ANALYSIS (TRANSCEIVER CASE).

(Col. 1) Freq, MHz	(2) IM Level at Xmtr, dBm	(3) Xmtr Cplr Atten, dB	(4) Level at Rcvr Subsys, dB	(5) Atmos Noise at Rcvr Subsys, dBm	(6) Excess IM, dB
2	-12	40	-52	-87	+35
4	-12	40	-52	-95	+43
6	-12	40	-52	-100	+48
8	-12	40	-52	-103	+51
10	-12	40	-52	-106	+54
12	-12	40	-52	-108	+56
15	-12	40	-52	-111	+59
20	-12	40	-52	-114	+62
25	-12	40	-52	-117	+65
30	-12	40	-52	-119	+67

(6) TRANSMITTER HARMONIC OUTPUTS (TABLE 31)

Table 31 presents the analysis for the level of the second-harmonic output of the transmitter at the receiving subsystem input for the transceiver case. The third-harmonic level is estimated to be about 10 dB less. The harmonic levels are so high that the only remedy appears to be to leave the harmonic frequencies unassigned for receiving purposes.

TABLE 31. TRANSMITTER HARMONIC OUTPUTS (TRANSCEIVER CASE).

(Col. 1) Freq F_0, MHz	(2) Freq $2F_0$, MHz	(3) 2nd Hmnc at Xmtr, dBm	(4) Xmtr Cplr Atten, dB	(5) Level at Rcvr Subsys, dBm	(6) Atmos Noise at Rcvr Subsys, dBm	(7) Excess 2nd Hmnc, dB
2	4	+15	60	-45	-95	50
4	8	+15	60	-45	-103	58
6	12	+15	60	-45	-108	63
8	16	+15	60	-45	-112	67
10	20	+15	60	-45	-114	69
12	24	+15	60	-45	-117	72
15	30	+15	60	-45	-119	74

(Third-harmonic levels are about 10 dB less than these values)

COMMON-TRANSMIT/RECEIVE-ANTENNA CASE

In the arrangement using a common antenna for both transmitting and receiving, separate transmitters and receivers are used instead of transceiver-type equipments. When this is done, both transmitting and receiving multi-couplers are used in the normal manner except both are connected to the same antenna. Since the receiving frequencies are no longer tied to the transmitting frequencies as they are in transceiver-type operation, separations of 2½% from transmitting to receiving frequency can be considered.

(1) FIXED DECOUPLING NETWORK

A transmitting antenna, which must be highly efficient in order to perform its transmitting function, cannot provide the antenna deficiency needed by the receiving subsystem to minimize interference from local transmitters. A fixed decoupling network is used to provide the equivalent of the receiving antenna deficiency. Notice that this decoupling network will not have the same characteristics the decoupling network used in the transceiver case had. Table 14, previously derived, gives the attenuation-versus-frequency characteristic for the new decoupling network.

(2) RECEIVE CROSS MODULATION (TABLE 32)

The cross modulation limitation of the R-1051 receiver is about -10-dBm power level at the receiver input for a frequency 2½% from the frequency to which the receiver is tuned. The output power of the transmitter is attenuated by the transmitting coupler on-channel loss, by the decoupling network attenuation, and by the receiving multicoupler attenuation at 2½% from the receiver tuned frequency.

Table 32 presents the analysis. At frequencies above about 4 MHz the cross modulation power limitation at the receiver input is not met, the excess being 34 dB at 30 MHz. Three possibilities exist to improve the performance. One is to improve the receiver cross modulation performance by added selectivity in the receiver. The second is to provide an auxiliary tunable network between receiving multicoupler output and receiver input which tracks the receiver and multicoupler tuning. The third is to relax the transmit-to-receive frequency separation sufficiently to obtain 34 dB added attenuation. This would require increasing the minimum frequency separation to approximately 5%.

TABLE 32. RECEIVER CROSS MODULATION ANALYSIS (COMMON-T/R-ANTENNA CASE).

(Col. 1) Freq, MHz	(2) Xmtr Output, dBm	(3) Xmtr Cplr Loss, dB	(4) Decplr Network Atten, dB	(5) Rcvr Cplr Atten, 2½%, dB	(6) Total Atten, dB	(7) Level at Rcvr Subsys, dBm	(8) CM Limit at Rcvr Subsys, dBm	(9) Added Atten Needed, dB
2	+60	2	26	56	84	-24	-10	-14
4	+60	2	20	49	71	-11	-10	-1
6	+60	2	17	45	64	-4	-10	+6
8	+60	2	15	43	60	0	-10	+10
10	+60	2	13	41	56	+4	-10	+14
12	+60	2	11	39	52	+8	-10	+18
15	+60	2	9	37	48	+12	-10	+22
20	+60	2	7	34	43	+17	-10	+27
25	+60	2	5	32	39	+21	-10	+31
30	+60	2	4	30	36	+24	-10	+34

(3) RECEIVER INTERMODULATION

The calculations for receiver intermodulation are very similar to those for cross modulation, the principal difference being that the nearest interfering signal is located 5% from the receiver frequency rather than 2½%. This provides an added selectivity in the receiving multicoupler of 24 dB. Therefore, the total attenuation is 24 dB greater than that given in table 32, column 6, and the added attenuation needed, column 9, is 24 dB less. Thus, the receiver intermodulation limit, which is the same as the cross modulation limit, is exceeded only at frequencies above 20 MHz.

(4) LIABILITY TO BURNOUT DAMAGE

Table 19 and the text immediately preceding it fully analyzed this situation. It will not be repeated here. However, the analysis showed that the receiving multicoupler is exposed to excessive voltages or po' er levels.

One way being considered to alleviate this situation is to take advantage of the broadband antenna arrangement by restricting the receiving facilities in a manner such that at the higher frequencies, at which the decoupling network attenuation is low, the transmitters and receivers are effectively connected to separate antennas with space isolation between them. For example, the 2-to-6-MHz broadband antenna is used only for 2-to-6-MHz transmitting, but for receiving over the entire frequency band to 30 MHz. The 4-to-12-MHz and 10-to-30-MHz broadband antennas are to be used for transmitting only. Thus, at frequencies above 6 MHz the receiving multicouplers and receivers are effectively on a separate antenna from the transmitters in their frequency range. This provides the space isolation existing between the broadband antennas as an added protection. This averages from 16 dB at 6 MHz to 36 dB at 30 MHz – sufficient to reduce the receiving multicoupler exposure to acceptable values.

(5) TRANSMITTER BROADBAND NOISE (TABLE 33)

The transmitter broadband noise is attenuated only by the transmitting multicoupler selectivity before reaching the input to the decoupling network. At this point its level is compared with that of the atmospheric noise.

Table 33 shows the analysis. At 2½% separation between transmitting and receiving frequencies the available attenuation is inadequate, 37 dB to 68 dB additional attenuation being required. At 5% frequency separation the performance standard is reasonably well met below about 10 MHz. Above 10 MHz a frequency separation estimated at 8% is needed.

TABLE 33. TRANSMITTER BROADBAND NOISE ANALYSIS (COMMON-T/R-ANTENNA CASE).

(Col. 1) Freq. MHz	(2) URT-23 Xmtr Noise 2½% dBm	(3) URT-23 Xmtr Noise 5% dBm	(4) Xmtr Cplr Atten 2½% dB	(5) Xmtr Cplr Atten 5% dB	(6) BB Noise at Rcvr Subsys 2½% dBm	(7) BB Noise at Rcvr Subsys 5% dBm	(8) Atmos Noise at Rcvr Subsys, dBm	(9) Added Atten Needed 2½% dB	(10) Added Atten Needed 5% dB
2	-22	-44	28	40	-50	-84	-87	37	3
4	-30	-52	28	40	-58	-92	-95	37	3
6	-34	-56	28	40	-62	-96	-100	38	4
8	-36	-58	28	40	-64	-98	-103	39	5
10	-37	-59	28	40	-65	-99	-106	41	7
12	-37	-60	28	40	-65	-100	-108	43	8
15	-36	-50	28	40	-64	-100	-111	47	11
20	-32	-58	28	40	-60	-98	-114	54	16
25	-28	-56	28	40	-56	-96	-117	61	21
30	-23	-52	28	40	-51	-92	-119	68	27

(6) TRANSMITTER-GENERATED INTERMODULATION

The analysis and results for transmitter-generated intermodulation for the common-transmit/receive-antenna case are the same as for the transceiver case. Table 30 applies and is not repeated here.

(7) TRANSMITTER HARMONIC OUTPUTS

The analysis and results for transmitter harmonic outputs for the common-transmit/receive-antenna case are the same as for the transceiver case. Table 31 applies and is not repeated here.

SUMMARY AND RECOMMENDATIONS

SUMMARY

Several variations of a hf shipboard communication system are analyzed. Special attention is given to the characteristics needed to protect the (S + N)/N ratio at the receiver output from excessive degradation due to interference from transmitters operating on the same ship while maintaining maximum usable receiver sensitivity. The analysis procedure is outlined; a reference system with assumed characteristics is analyzed; and actual measured characteristics of current types of equipments are utilized and the shortcomings of the equipments with respect to system demands determined.

A basic design assumption made is that the system should be so proportioned that the S/N ratio at the receiver input at times of quasi-minimum atmospheric noise should not be impaired by more than 3 dB by the receiver internal noise or by any of the interference effects of local transmitter operation. Minimum frequency separations of 5% between transmitting frequencies used simultaneously and 2½% between transmitting and receiving frequencies used simultaneously are the design goals established.

Current types of equipments assumed are the AN/URT-23(V) Radio Transmitter, the R-1051-D/URR Radio Receiver, the AN/SRA-56/57/58 Antenna Couplers for transmitting, and the AN/SRA-38/39/40/49 Antenna Couplers for receiving. Three basic types of operation are studied: transmitters and transmitting multicouplers on one antenna, receivers and receiving multicouplers on a separate antenna; a transceiver-type operation with one antenna for both transmitting and receiving; and a nontransceiver type of operation with both transmitters and receivers connected to the same antenna. Antenna system characteristics used approximated those found on the DLG 26 type ship.

One unexpected conclusion that has resulted from this study is that the requirements for interference-free operation are harder to meet at the high-frequency end of the band than they are at the low-frequency end. Previously, the intuitive feeling was that interference problems were more severe at the lower end of the band. The variation of the quasi-minimum atmospheric noise with frequency is such that the usable sensitivity of the system is reduced at the lower frequencies, and, hence, the demands on interference suppression characteristics are less severe than at the high frequencies.

Shipboard applications in which transmitters and receivers must operate simultaneously in close electrical proximity to each other have special design requirements that may not be essential for other applications.

Only the system arrangements which demand the most stringent equipment performance are treated in this summary. If limits for these conditions are met, the system performance under less demanding circumstances will be more than satisfactory. In general, the most demanding arrangement is that in which a common antenna is used simultaneously for both transmitting and receiving with nontransceiver-type operation.

The most serious obstacle to satisfactory system performance is transmitter broadband noise. With the AN/URT-23 transmitter and 2½% separation between transmitting and receiving frequencies, the broadband noise is 37 dB to 68 dB above the desired limit, depending upon the frequency. If the transmitter design cannot be improved sufficiently, perhaps by the insertion of low-level or output-level filtering, or if the transmitting multicoupler selectivity cannot be increased, the only apparent remedy is to increase the minimum separation between transmitting and receiving frequencies. A frequency separation of about 8% is required, particularly at the high end of the band. At the low end of the band the required separation is about 5%.

Transmitter-generated intermodulation and transmitter harmonic outputs are less serious problems than broadband noise, inasmuch as these phenomena produce spot-frequency interferences rather than wiping out a band of frequencies as broadband transmitter noise does. Also, antenna environment-generated intermodulation products fall on exactly the same frequencies and, in fact, are indistinguishable from transmitter-generated intermodulation without careful measurements. Transmitter-generated intermodulation levels are 35 dB to 67 dB and transmitter second-harmonic levels are 50 dB to 74 dB above the desired limits. The transmitter performance can be improved with respect to these characteristics by improvement of the linearity of the power amplifier or by an increase in the output filtering, either in the transmitter itself or in the associated transmitting multicoupler. The antenna environment-generated intermodulation aboard the average ship is about 60 dB above 1 microvolt. With special effort this level appears to be reducible by about 30 dB, or to a level of about -57 dBm. This is just about equal to the level of the transmitter-generated intermodulation, which is -52 dBm. Thus, substantial expense is not justified in attempting to reduce transmitter intermodulation levels in transmitters for shipboard applications until assurances are available that the average antenna environment-generated intermodulation level can be further reduced. Until substantial improvement is achieved, frequency assignments should be so selected that low-order intermodulation products do not fall on receiving frequencies.

In the receiving subsystem the major problem probably is to devise a means of protecting the receiving multicoupler against disability or damage during local transmitter operation, particularly in the common-transmit/receive-antenna case with nontransceiver-type operation. A fixed decoupling network is inserted in the receiving subsystem, and this network must be designed to withstand the combined power of up to eight transmitters. In size and voltage-handling capabilities it should resemble transmitting-type components. While this network has considerable attenuation at the lower frequencies (26 dB), its attenuation is small at the higher frequencies (4 dB). The receiving multicoupler is exposed to voltages corresponding to power levels of 20 to 1600 watts.

One way to alleviate this situation is to transmit only 2 to 6 MHz on one broadband antenna but to use this antenna for receiving over the entire frequency band to 30 MHz; and then to transmit signals in the 4-to-12-MHz band on a second broadband antenna and signals in the 10-30-MHz band on a third broadband antenna. In the 2-6-MHz frequency range, the decoupling network provides reasonable protection for the receiving multicouplers, limiting the exposure to voltage levels corresponding to 178 watts maximum. In the frequency range above 6 MHz transmission takes place on separate broadband antennas, and the space isolation is added to protect the receiving multicoupler.

In this systems study it has been assumed that the receiver performance with respect to receiver intermodulation and desensitization is adequately represented by the receiver cross modulation characteristics. In general, the cross modulation performance of the R-1051 receiver is satisfactory at the low-frequency end of the band and up to a frequency of about 5 MHz. Above 5 MHz an increasing amount of improvement is needed, until at 30 MHz the desired improvement reaches 34 dB. This improvement could be obtained by added selectivity in the receiver front end or in the receiving multicouplers, or by improved mixer characteristics in the receiver.

The receiver noise figure of the R-1051 receiver has been measured as approximately 12 dB over the major portion of its operating level. Any obtainable improvement in this noise figure could be used to increase the receiving multicoupler selectivity or to increase the permissible antenna deficiency.

RECOMMENDATIONS

1. It is recommended that the analysis methods outlined in this report be applied in hf communication system design to achieve a balanced system in which receiving subsystem sensitivity and transmitter-to-receiver interference effects are properly proportioned to the inherent levels of quasi-minimum atmospheric noise. This involves matching receiving subsystem internal noise to the quasi-minimum atmospheric noise over the frequency band.

2. It is recommended that major attention be devoted to the reduction of transmitter broadband noise. This probably can be best accomplished either by additional low-level filtering between exciter and power amplifier stages of the transmitter or by additional filtering at the high-level output. This improvement is essential if minimum frequency separation between transmitting and receiving channels is to obtain.

3. Only minor efforts to reduce transmitter harmonic outputs and transmitter-generated intermodulation products of shipboard transmitters seem to be justified until assurances are obtainable that the antenna environment-generated intermodulation products can be substantially reduced aboard naval ships.

4. Only minor improvements in receiver noise figure and in receiver cross modulation performance seem to be indicated, and these only at the high end of the frequency band. In general, current receiver performance appears to be satisfactory when incorporated in a properly designed system.

5. Receiving multicouplers may require some redesign to insure satisfactory operation without disability or damage when exposed to local transmitter power levels. This is particularly true for the case in which a common antenna is used simultaneously for both transmitting and receiving with non-transceiver-type operation.

6. Shipboard antenna systems, when properly designed and proportioned, appear adequate to meet the sensitivity and interference susceptibility demands of hf communication systems.

7. When a narrowband whip antenna with an antenna tuner is used for transmitting, the selectivity of the antenna tuner is so low that a filter should be added having essentially the same selectivity characteristics as one channel of a transmitting multicoupler. The antenna tuner is essentially an impedance-matching device and does not provide adequate selectivity.

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13. ABSTRACT

A design technique based on obtaining equality of quasi-minimum atmospheric noise and receiver internal noise at the receiving subsystem input is established and applied to three representative system arrangements. Special attention is given to the characteristics needed to protect the (S + N)/N ratio at the receiver output from excessive degradation due to interference from transmitters operating on the same ship while maintaining maximum usable receiver sensitivity.

An unexpected conclusion is that requirements for interference-free operation are harder to meet at the high-frequency end of the band.

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